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ABSTRACT

The phaseout of hydrochlorofluorocarbon (HCFC)-22 will require manufacturers of air-conditioning and refrigeration equipment to find suitable alternatives for this widely-used refrigerant. The R-22 Alternative Refrigerants Evaluation Program (AREP) was established by the Air-Conditioning and Refrigeration Institute (ARI) to assist manufacturers in obtaining performance data on a multitude of R-22 and R-502 alternatives.

One step in AREP is the testing of standard systems, modified for use with a given alternative refrigerant. Results from these "soft-optimized" system tests are summarized and evaluated for two compositions each of two different refrigerant blends. Various techniques were employed to "soft-optimize" systems, with varying efficacy.

No single alternative appears as a universal replacement for R-22. Furthermore, it is noted that the AREP tests represent only a first step in manufacturers' efforts to bring next-generation equipment to the marketplace.

INTRODUCTION

Earlier papers have described the importance and development of ARI's R-22 Alternative Refrigerants Evaluation Program (AREP)[1,2]. Also, summaries of results from AREP compressor calorimeter and system drop-in tests have been presented previously[2,3].

So far, test reports covering 20 refrigerants have been reviewed and accepted by the Technical Committee. Sixteen of these are possible R-22 replacement candidates: R-134a, R-290, R-717, R-32/125 (50/50 and 60/40), R-32/134a (20/80, 25/75, 30/70 and 40/60), R-125/143a (45/55), R-32/125/134a (10/70/20, 23/25/52, 24/16/60, 25/20/55 and 30/10/60), and R-32/125/290/134a (20/55/5/20). Six have been tested as possible R-502 replacements: R-125/143a (45/55 and 50/50), R-32/125/134a (10/70/20 and 20/40/40), R-32/125/143a (10/45/55), and R-125/143a/134a (44/52/4). It is recognized by the participants that there will not likely be a universal substitute for either R-22 or R-502; some substitutes may be better suited for certain applications than for others. The vast majority of the soft-optimized testing conducted to date as part of AREP centers upon two compositions each of two different refrigerant blends listed above. This paper summarizes results from these four R-22 alternatives.

Due to limited resources, not every possible candidate could be evaluated under AREP. The fact that a refrigerant has been tested under AREP does not constitute an endorsement of it by ARI or its member companies. Similarly, the fact that a refrigerant has not been tested under AREP does not necessarily indicate that ARI or its member companies consider it to be an impracticable candidate.

TESTING PROGRAM

In assessing a refrigerant's performance, three major comparisons with R-22 or R-502 must be made: (1) compression characteristics (e.g., efficiency, capacity, input power to the compressor, discharge temperature and discharge pressure); (2) heat transfer characteristics (in evaporation and condensation); and, finally (3) performance of the entire system. To make these comparisons, an evaluation program was organized, consisting of compressor calorimeter, system drop-in, and heat transfer tests, followed by testing of redesigned "soft-optimized" systems.

Testing of Systems

Based on the results of the compressor calorimeter and system drop-in tests and some early heat transfer testing, some candidate refrigerants have been tested in complete systems. These systems have undergone a first level optimization ("soft-optimization") for the particular test fluid. The systems were tested under standard conditions for the equipment under evaluation. The performance achieved using the alternative refrigerant was evaluated relative to R-22 or R-502 in the baseline (unmodified) system.

To soft-optimize the system for the alternative refrigerant, manufacturers performing the tests decided what types of modifications to make to the system, choosing within guidelines set by the AREP Technical Committee. Manufacturers may have varied one or more of the following: lubricant; compressor displacement; refrigerant charge; flow control (i.e., expansion device); motor size; heat exchanger circuiting and/or size; compressor speed; and size of accumulators. In addition, some manufacturers added a liquid-line/suction-line heat exchanger to the modified system.

RESULTS AND DISCUSSION

General Overview

Performance ratios were calculated to normalize the data from different reports and make them more comparable. Examining the capacity and efficiency of the alternative refrigerants as a ratio to those of the baseline helps to eliminate some of the variability between systems, testing conditions, etc., although these variables cannot be totally removed.

When using the results, several limitations must be recognized. Complex mathematical/statistical analyses of the data have not been performed, and probably cannot be performed to any high level of confidence due to the limited amount of data and the differences between various tests. The trends discussed should not be viewed as universally applicable, as they generally represent results from only a few types of systems. It should also be stressed that these results come from short-term tests of equipment originally designed for the baseline refrigerant (R-22 or R-502), modified to varying degrees for the alternative.

The modified systems do not represent equipment that is available in the marketplace today. Therefore, the results discussed below may not be truly indicative of the performance that will be achieved by equipment designed for the alternative refrigerants. More engineering work will be needed before manufacturers can produce, in sufficient quantities, equipment using these or other alternative refrigerants. This may represent an opportunity to improve upon the performance levels indicated by the AREP soft-optimization tests. On the other hand, engineering and economic tradeoffs that will be necessary to bring new systems to the market, may reduce the performance of the systems.

A graph of performance ratios achieved with the alternative is provided for the refrigerants analyzed. Each data point represents results from a single test using the alternative refrigerant (in the modified system) relative to the results achieved using the baseline refrigerant (in the original system) under similar test conditions. Noted next to each data point are the major items, if any, that were modified for the soft-optimized test. The reader should refer to the individual soft-optimized system test reports for a more complete description of how the system was changed for the alternative refrigerant. Furthermore, these graphs only summarize some of the results (e.g., system pressures are not discussed); the reader should refer to the individual test reports for more details of the tests performed and discussion of the results. The reader should also refer to the test reports for more details regarding the conditions at which the system was tested and for further analysis of the test results. These reports, along with AREP compressor calorimeter and system drop-in test reports, are publicly available[4].

Causes of large scatter in the graphs are explained where appropriate. There are several variables that may cause some of the scatter seen in the data, including: different type of system (e.g., a split system heat pump vs. a room air conditioner); different system size (in terms of tons, motor horsepower, etc.); different type of compressor (rotary, scroll, screw, reciprocating, etc.); different refrigerant charge; different lubricant; different testing conditions (e.g., indoor/outdoor temperatures); different amount of subcooling; different amount of superheat; different test facilities and equipment; and, of course, experimental error. Also, the type and nature of the system modifications varied from test to test, certainly affecting the results achieved. In addition, differing sets of thermophysical data were sometimes used by the manufacturers; therefore, discrepancies in calculated performance values may have arisen solely from the use of these different thermophysical property databases.

The refrigerants are evaluated below in no particular order.

R-32/125 (60/40)

Data were received for several systems, ranging from small room-units (less than 1 ton) to a 5 ton split system heat pump (SSHP). Performance results are shown in Figure 1.

Results. Cooling capacities with the modified systems range from 3% below to 7% above the baseline (i.e., R-22 in the original equipment). Efficiencies also varied somewhat, from 90 to over 105% of the baseline. Capacities in the heating mode were similar to baseline tests, ranging from 97 to 104% of R-22. All heating tests except one showed efficiencies below the baseline, with efficiency ratios ranging from 0.97 to 1.01.

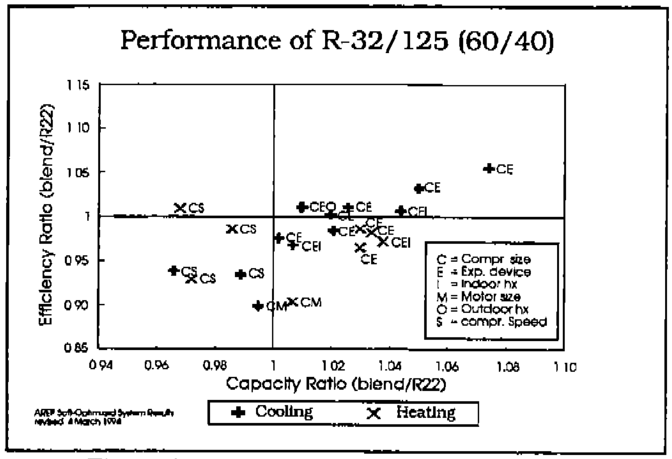

Figure 1. *Performance of R-32/125 (60/40)*

Discussion. Compared to drop-in test results of this blend, capacities in the soft-optimized tests have been reduced. It is likely that changes in the compressor were responsible for lowering capacities to around par with R-22. For instance, the compressor displacement was decreased, by 25 to 37%, in all the soft-optimized system tests with this blend. Also, some manufacturers decreased the compressor operating frequency, by 9 to 17%. This also has the effect of lowering capacities, as was seen in many AREP drop-in tests[2].

Data supplied by Japanese manufacturers showed consistently worse performance (capacity and efficiency ratios) than U.S. data. This may be a function of the type of equipment tested, or it may have arisen from the use of differing thermophysical databases. The Japanese manufacturers used one set of thermophysical data, and three of the reports from U.S. manufacturers used a second set. A third set was used by the remaining test report (the 2.5 ton air-conditioner), and, it is interesting to note that data from those tests showed the highest capacity ratios and the highest efficiency ratios of all the soft-optimized tests of this blend.

A few manufacturers ran cooling tests with the soft-optimized equipment under both DOE A and DOE B conditions. In all of these cases both the capacity and efficiency ratios under DOE B conditions were better than under DOE A conditions. This suggests that this blend may see more benefit than R-22 does from running at less severe (e.g., DOE B) conditions, and, conversely, may suffer more penalty under harsher (e.g., DOE A) conditions. However, note that in some of these tests, the refrigerant charge was chosen to optimize the efficiency at DOE B conditions; this of course is at least partially responsible for the good performance ratios achieved under DOE B cooling tests.

A 2 ton SSHP was run under two soft-optimized configurations. The modifications made were identical except that in the second set, the indoor heat exchanger circuitry was reconfigured from 4-4 to 3-3 (paths in-out). This change seems to have had only minor effects, possibly due to the azeotropic nature of the refrigerant (i.e., very little glide to take advantage of, so recircuting heat exchanger may not help), or possibly because the heat exchanger needs to be redesigned further to take advantage of the heat transfer characteristics of this blend. Capacity and efficiency ratios achieved using the re-circuited heat exchanger, under DOE A, B and E conditions, remained within ±2% of the first set of soft-optimized results.

R-32/125 (50/50)

This blend is similar to the R-32/125 (60/40) blend originally nominated for testing, except that the amount of R-32 has been lowered to reduce flammability risks. Results are plotted in Figure 2.

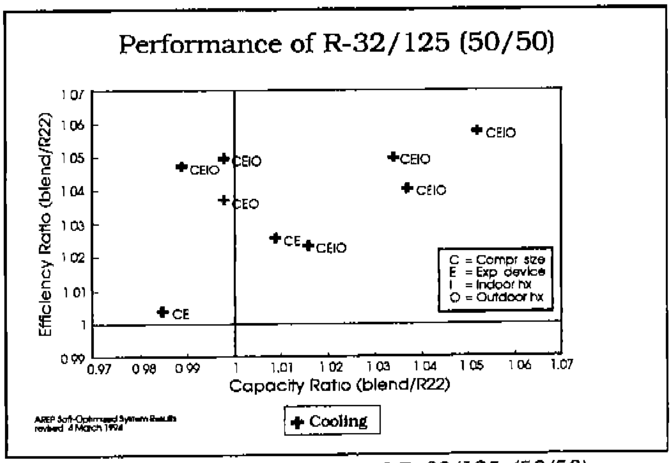

Figure 2. *Performance of R-32/125 (50/50)*

Results. Capacity ratios, ranging from 0.98 to 1.05, were similar to those achieved with the 60/40 mixture. Cooling efficiencies of the soft-optimized systems were all above the baseline R-22 equipment, by 1 to 6%. No AREP data have yet been presented for systems tested in the heating mode with this blend.

Discussion. Compared to results with the 60/40 blend, a 2.5 ton (reciprocating) air-conditioner showed an approximately 5% decrease in capacity and 2% loss in efficiency. A 5 ton SSHP experienced a small (around 1%) decrease in capacity relative to the 60/40 mixture, but its efficiency increased by about 3%.

As with the 60/40 mixture, those units which were tested under both DOE A and B conditions, showed higher capacity and efficiency ratios under the DOE B tests.

A 2.5 ton (reciprocating compressor) air-conditioner was tested under two soft-optimized configurations. Both employed a new compressor and a new expansion device, but one set of tests used redesigned heat exchangers, changing the indoor heat exchanger circuitry from 6-6 to 3-3 paths and the outdoor circuitry from 2-1 to 1-1 paths. These changes increased performance slightly (capacities by 3-5%, efficiencies by 1-4%).

R-32/125/134a (30/10/60)

Data were received from several air-conditioning products, up to about 3 ton capacity. Capacity and efficiency ratios are plotted in Figure 3.

Results. Capacities achieved in the soft-optimized equipment were within ±5% of those achieved in the unmodified, R-22 systems. With the exception of a window unit, all cooling tests showed a drop in efficiency; efficiency ratios ranged from 0.90 to 1.02. With one exception, all heating capacities were close to R-22, ranging from 96 to 105% of the baseline capacity. Efficiencies ranged from 13% below to equal to the baseline, with one exception. The exception, with a capacity and efficiency ratio of 0.81 and 0.83, respectively, is discussed below.

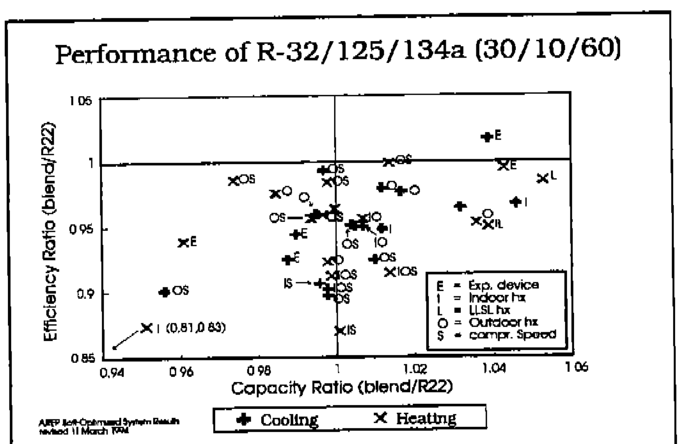

Figure 3. *Performance of R-32/125/134a (30/10/60)*

Discussion. This blend is zeotropic and will experience a temperature glide of approximately 5°C (9°F), offering the potential of increasing performance by use of counterflow heat exchangers. Many manufacturers attempted to take advantage of this by redesigning the circuitry of the outdoor and/or indoor heat exchanger. Although pure counterflow was not reached, many redesigned heat exchangers achieved a cross-counterflow arrangement, and this likely contributed to the overall increase in efficiencies (vs.

drop-in results). The reader should consult the individual AREP reports for more details regarding the original and modified heat exchangers, and how the performance of any particular piece of equipment was affected.

Some equipment was also tested at modified compressor speeds, as indicated in the figure. These speeds were approximately the same (93 to 105%) as those used in the baseline systems, and therefore likely had only a minor impact on the performance of the soft-optimized systems.

One exception to the performance trends seen with this blend came from a heating test of a 2 ton SSHP. First, this unit was tested without any significant modifications. Next, the indoor heat exchanger was reconfigured. This change did not affect the unit's performance under the DOE A cooling test, but did help increase capacity ratios under DOE B conditions from 1.03 to 1.05 and efficiency ratios from 0.96 to 0.97. This minor gain in cooling was accompanied, however, by a severe drop in heating performance. Under DOE E conditions, capacity and efficiency ratios fell from 1.00 to 0.81 and from 0.96 to 0.83, respectively. A liquid-line/suction-line heat exchanger was added to this modified system, bringing heating (DOE E) performance results back close to the baseline. Although the modified unit with the liquid-line/suction-line heat exchanger was not tested in the cooling mode, theoretical evaluations suggest that cooling performance may also be enhanced slightly[5].

R-32/125/134a (23/25/52)

This blend is similar to the R-32/125/134a (30/10/60) blend originally nominated for testing, except that the composition has been changed to reduce flammability risks. Results are plotted in Figure 4.

Results. Performance in the cooling mode with this blend was comparable to the performance seen with the 30/10/60 blend. Capacity ratios ranged from 0.93 to 1.01 and efficiency ratios were between 0.90 and 0.97. Equipment using this blend also showed heating results similar to the 30/10/60 blend. Heating capacities were within ±2% of the baseline, and efficiencies ranged from 7% below to 2% above the baseline.

Discussion. Compared to results with the 30/10/60 mixture, a WRAC showed an approximately 3% decrease in capacity and 5% loss in efficiency. Two rotary-driven SSHPs tested with the 23/25/52 blend showed performance comparable to that seen by the six rotary-driven SSHPs tested with the 30/10/60 mixture.

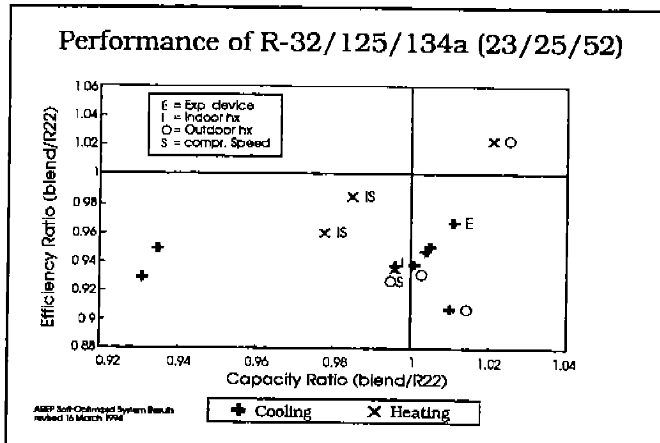

Figure 4. *Performance of R-32/125/134a (23/25/52)*

Data Availability

All draft test reports are submitted to the AREP participating companies for review. Upon approval by the AREP Technical Committee and the AREP Task Force, test reports are made available to the public[4].

CONCLUSIONS

The results above show that there are some non-ozone-depleting candidates whose performance approaches that of R-22 in the systems reviewed. Some of the refrigerants listed above can equal or better the capacity and/or efficiency of the R-22 baseline system after some minor changes. Full optimization of systems still needs to be performed, and may help improve the performance of these refrigerants; however, this work will not be done under the AREP effort. Also, much more additional work needs to be performed by individual manufacturers before new equipment can be commercialized, including long-term reliability testing, cost-benefit analyses of possible system modifications, retooling of manufacturing lines, etc.

Based on the AREP work, there is no obvious choice of one single refrigerant to immediately replace R-22 or R-502. In fact, it is likely that marketplace forces will support different choices to replace these refrigerants for various applications. Also, there may be other viable candidates that were not looked at by AREP. In no way should the list of AREP refrigerants be considered a definitive list of all the possible R-22 and R-502 replacement candidates.

In many cases, the results (capacity and efficiency ratios) show good agreement, despite the fact that different types and sizes of equipment were tested, with different types of modifications performed, by different manufacturers using different testing facilities. Of course, presenting results normalized to baseline refrigerants eliminated some of the variability between tests. But the consistency in the results is also due to the efforts of the AREP participants in conducting their tests under standardized conditions.

Soft-optimized system tests are envisioned as the last step in the AREP testing program. Other work that has been or is being performed as part of AREP includes compressor calorimeter, system drop-in and heat transfer testing. Furthermore, the AREP effort is just one complimentary program in the industry's endeavors to develop new quality equipment that runs on alternative refrigerants. For instance, full optimization of compressors and systems, not being conducted under AREP, is certainly warranted, but will be left up to individual companies to perform.

The AREP effort so far has been a success. The program has provided much-needed data on several R-22 and R-502 alternatives in an efficient manner. This data will be useful to manufacturers in supplementing other available data on the performance of alternative refrigerants, as well as confirming the results of their own tests. In addition, these performance results, along with future performance results and information on a host of other issues such as flammability, toxicity, availability, etc., will assist manufacturers in deciding which refrigerant(s) to pursue for use in their equipment.

But perhaps the most significant accomplishment of AREP has been the recognition by the air-conditioning and refrigeration industry that, even in a very competitive environment, there are often advantages in cooperation.

ACKNOWLEDGEMENTS

The data analyzed in this paper come from soft-optimized system test reports supplied by various AREP participating companies. These tests were performed in these companies' laboratories at their own expense. ARI also thanks the Electric Power Research Institute (EPRI) for its assistance in funding and managing much of the heat transfer research being conducted under the AREP program. ARI also acknowledges the United States Department of Energy (DOE) for support of the Air-Conditioning and Refrigeration Technology Institute (ARTI) Refrigerant Database, one of the means by which AREP reports are being made available to the public.

REFERENCES

1. Glenn C. Hourahan and David S. Godwin, *ARI's R-22 Alternative Refrigerants Evaluation Program (AREP)*, 29 September 1992, from the *Proceedings of the 1992 International CFC and Halon Alternatives Conference.*
2. David S. Godwin (ARI), *Results of System Drop-In Tests in ARI's R-22 Alternative Refrigerants Evaluation Program*, 1 December 1993.
3. David S. Godwin and Mark S. Menzer (ARI), *Results of Compressor Calorimeter Tests in ARI's R-22 Alternative Refrigerants Evaluation Program (AREP)*, September 1993, from the *Proceedings of the 1993 International CFC and Halon Alternatives Conference.*
4. *Results from ARI's R-22 Alternative Refrigerants Evaluation Program (AREP): Volumes 1-4 (Compressor Calorimeter, System Drop-In, Soft-Optimized System, and Soft-Optimized Compressor Test Reports).*
5. Piotr A. Domanski and David A. Didion (National Institute of Standards and Technology), *Theoretical Evaluation of R-22 and R-502 Alternatives*, January 1993.